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Slave LIN Driver for the MC68HC908QT/QY Family

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Introduction

This application note describes a slave LIN (local interconnect network) driver that complies with LIN Specification 1.3 and fits on Motorola's smallest 8-bit microcontroller with sufficient memory for a small application. The driver fits within the 1.5 K of FLASH memory on the small and inexpensive MC68HC(9)08QT/QY microcontroller unit (MCU). This shows that even the smallest Freescale 8-bit MCU can support LIN when properly configured.

The MC68HC(9)08QT/QY is a member of the M68HC08 Family. All members of the family use the enhanced M68HC08 central processor unit (CPU08) and are available with a variety of modules, memory sizes and types, and package types.

The source code, AN2503SW.zip, is written entirely in C and can be found at the Freescale LIN website, http:www.freescale.com.

Freescale offers a complete range of products to meet your varied needs. You can find more information about the complete LIN portfolio, including products, software, documentation, and training at Motorola's LIN website.

Also see **LIN Driver Features and Performance Comparison** for descriptions of Motorola's LIN drivers and implementations.

NOTE: *With the exception of mask set errata documents, if any other Freescale document contains information that conflicts with the information in the device data sheet, the data sheet should be considered to have the most current and correct data.*

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LIN Basic Concepts

LIN is a popular, low-cost serial communication system designed to support the lowest level of automotive networks in existing CAN networks with hierarchical designs. The lowest level of a hierarchical network, LIN enables cost-effective communication with sensors and actuators when all the features of CAN are not required.

LIN is a single-master/multiple-slave protocol. In a hierarchical network, a master is usually a more powerful microcontroller with other network interfaces available, like CAN. This allows several inexpensive slaves with minimum requirements and low complexity to perform different tasks under the control of one master. In this way, collisions are avoided and there is no need for bus arbitration. **Figure 1** shows this concept of communication.

LIN's main features are:

- Minimal hardware requirements — Only one bidirectional line of communication, allowing a baud rate as high as 20 kbps
- Synchronization frame available — No need for crystals or ceramic resonators, which is very useful in a low-cost environment
- Integrated routines — Data checksum in each frame and error detection in physical layer (bit error) and data link layer (two parity bits)
- Standard protocol — Based on the standard UART/SCI, which is very common, allowing easier debugging and a better understanding of the protocol

See **References and Recommended Links** for more information on LIN basic concepts.

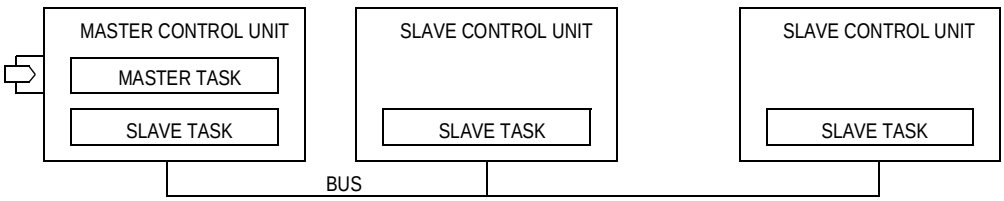

Figure 1. LIN Concept

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Error Detection

The slave must detect these errors:

- Bit error — When sending data, the data monitored on the bus is different from the bit value that is sent
- Checksum error — When receiving data, the sum of the inverted modulo-256 of received bytes plus the checksum is not 0xFF
- Identifier parity error — When receiving data, the expected ID parity bits are not equal to the received ones

Fault confinement depends on system requirements and is not part of the LIN specification. The most common procedure for fault confinement is performed by the master asking for the slave status flags.

LIN Driver Software Description

Because this LIN driver will be implemented in a very small MCU, there are several aspects that should be considered when implementing the driver:

- Small size — Size is dependent on the needs of the application and can be less than 650 bytes with minimum functionality or less than 1 K and support the LIN specification.
- High modularity — Based on the application needs, modules can be configured to enable or disable LIN functionality such as sleep mode, bit error checking, and parity checking. As modules are disabled, the code is reduced without affecting functionality.
- Flexibility — This driver supports sleep mode specification 1.3 and earlier versions. It can also be configured to manage IDs in different ways, so that the user can choose the best option for the application.
- Easy hardware changes — All I/O pins used can be configured easily to change according to the application needs.
- Minimal hardware required — Only one timer channel is used, allowing the user to use the second one; however, the timer is shared and the channels can't be managed simultaneously. If a transceiver isn't used, only one pin can be used for input and output (from the timer). If the transceiver is used, only two general-purpose I/O pins and the one used by the timer can be used. If sleep mode is enabled, $\overline{\text{IRQ}}$ can be used as an input, or a regulator will handle this functionality.

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Files Used for LIN Driver

The files used for the LIN driver are:

- Source files:
  - main.c — Contains driver initialization and the main application example. See **LIN Initialization** and **Driver Usage and Example**.
  - slave_drv.c — Contains all the functions available for the driver. See **Driver Functionality** for a detailed explanation.
- Header files:
  - slave_drv.h — Contains all the function definitions and macros used in slave_drv.c.
  - lincfg.h — For LIN configuration. See **lincfg.h Description**.
  - linmsgid.h — Contains the defined IDs. See **linmsgid.h Description**.
  - trimcfg.h — For configuring the trimming process. See **Trimming** and **trimcfg.h Description**.
  - resolver.h — Contains buffer definitions used in main program.
  - const_table.h — Contains buffers and ROM table definitions.

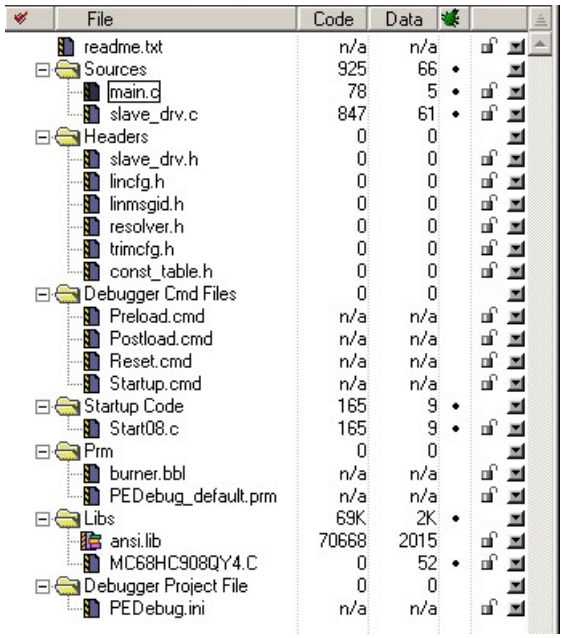

Figure 2. Files Used for the LIN Driver

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Variables Used in LIN Driver

Table 1 provides all the global variables used in this driver and their functions.

Table 1. LIN Driver Variables

Name	File	Function
*gpMyReceive	main.c	Pointer to a received buffer(1)
*gpMySend	main.c	Pointer to a transmission buffer(1)
gu8PreTrimmed	main.c	Pretrimmed value(2)
gu8CommBuffer[9]	slave_drv.c	I/O Buffer for transfer process
gu8RxShrReg	slave_drv.c	Reception shift register
gu8TxShrReg	slave_drv.c	Transmission shift register
gu8SwScdr	slave_drv.c	Emulated SCI data register
gu8P0	slave_drv.c	General-purpose register
gu8P1	slave_drv.c	General-purpose register
gu8Offset	slave_drv.c	Used to store the trimming offset
gu8IdOrData	slave_drv.c	Defines if arriving byte is ID or data
gu8MsgLength	slave_drv.c	Define expected length for the ID
*gpGeneral	slave_drv.c	Pointer used for transfer purposes
gu8TablePointer	slave_drv.c	Position of ID in ROM table
gu8BitCount	slave_drv.c	Bit counter
gu8InpMode	slave_drv.c	Actual mode of input capture
gu8OverMode	slave_drv.c	Actual mode of overflow
gu8RxErrCounter	slave_drv.c	Reception error counter(3)
gu8TxErrCounter	slave_drv.c	Transmission error counter(3)
gu8ErrReg	slave_drv.c	Error counter
gu8Parity	slave_drv.c	Parity status
gaMsgxxBuffer[ ]	const_table.h	Buffer defined for each ID(3)
gsTableType .u8ModLength .*pBufPtr .u8Id	const_table.h	ROM Table defining all declared vectors and the following properties: • Expected length for the ID • Pointer to the defined buffer • ID for this table entry

1. Used for example purposes
2. Accessed by slave_drv.c
3. Accessed by main.c

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Driver Functionality

The following is a description of the LIN implementation in an MC68HC908QY MCU. Some functionality may be more understandable if the MCU is familiar. More information on this MCU and its pinout can be found in the **MC68HC908QY4 Signal Description**.

Because this microcontroller doesn't have an SCI module, one channel from the timer will be used as an input and a general-purpose pin will be used as an output using the timer overflow functionality. To lower the costs, the internal oscillator can be used through the synch frame feature.

1. Initialize all variables.
2. Driver will perform all the functionality in the Interrupt service routines. In the idle state, it will wait for a new frame.
3. After a valid break is detected, all the following fields will be expected:
   a. Synch field (where trimming process may occur)
   b. Identifier field (where the slave task will be defined)
   c. Proper action will be executed (either reception or transmission)
      - Reception — Waits for the data fields to be defined, store definitions in the proper buffer and calculate checksum field.
      - Transmission — Sends the corresponding buffer and its checksum. If a sleep mode frame is detected, the MCU will either enter low power-consumption mode, or it will power off if a regulator is used.

The flow diagram of the driver can be seen in **Figure 3**.

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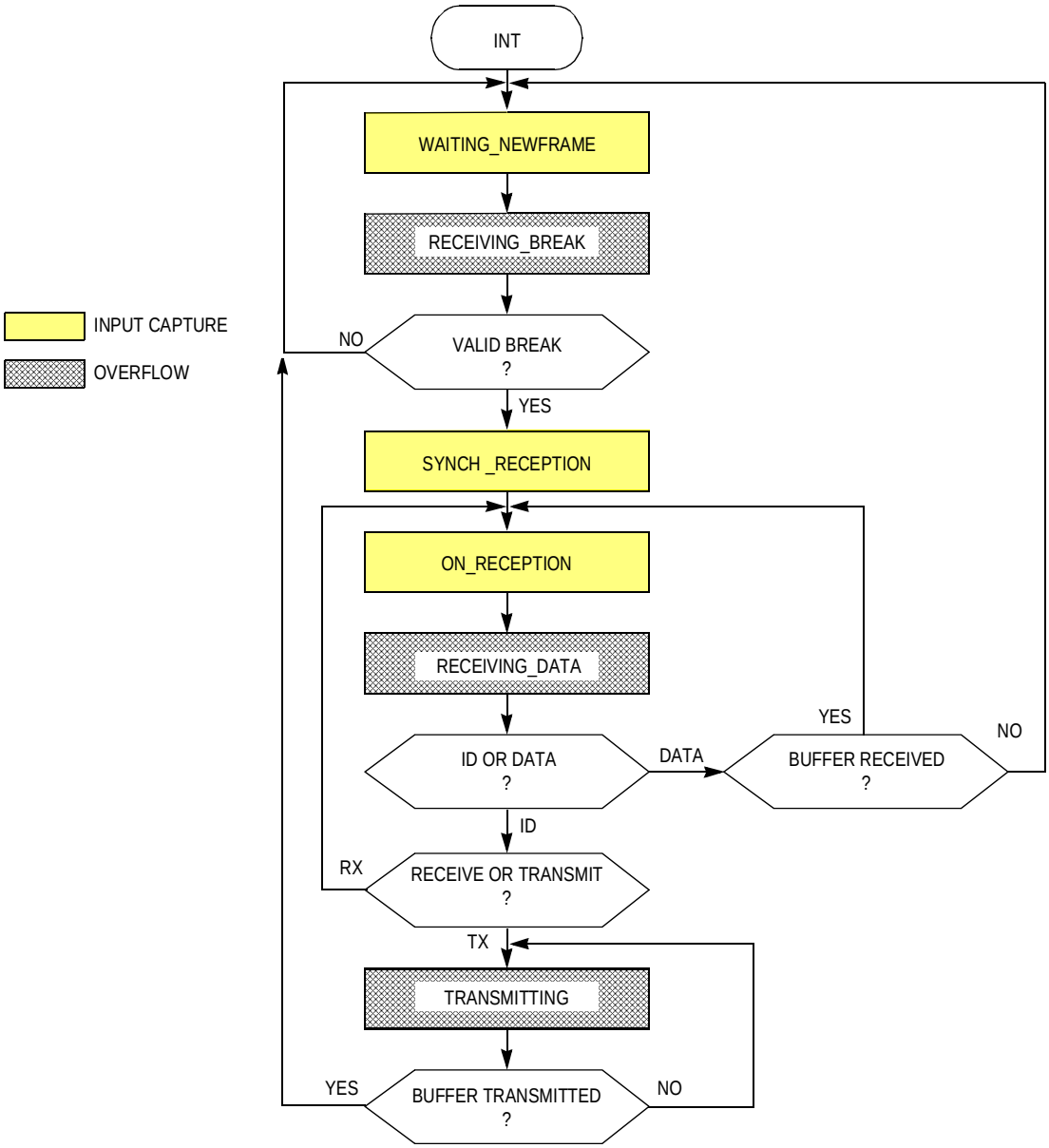

Figure 3. LIN Driver Flowchart

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LIN Initialization

The main.c file contains the basic structure for initializing this driver based on the lincfg.h file. Basically the registers that should be configured are:

- CONFIG1 and CONFIG2 — One-time writable registers used to initialize various options (internal/external oscillator, enable IRQ, COP disabled/enabled, etc)
- OSCTRIM — Specifies the size of the internal capacitor used by the internal oscillator (changes the oscillator frequency)
- Variables — All must be initialized to be used in this driver. This functionality is performed by **LINInit() function**

NOTE: *In the example, Start08.c doesn't initialize variables. Therefore, the user must ensure proper initialization of variables. All variables used by the driver are properly initialized in code.*

LINInit() function

This function initializes hardware and variables to a default state.

```
void LINInit( void )
 {
        #ifdef TWOPINS                          /* If two pins are defined for I/O, set output
pin*/
            SET_OUTPUT_PIN;
        #endif  /* TWOPINS */
        gu8InpMode = WAITING_NEWFRAME;          /* Set initial state */
        ChangeTimerConfig(INPCAPTURE);
        gu8IdOrData = ID;
         #ifdef CHECK_BIT_ERROR                 /* Initialize variables used for bit_error
checking */
                gu8ErrReg = 0x00;
                gu8TxErrCounter = 0x00;
        #endif
        gu8RxErrCounter = 0x00;                 /* Initialize error variables */
        #ifdef ENABLE_TRANSCEIVER
        TRANSCEIVER_ENABLE;
        #endif
        EnableInterrupts;
        return;
```

Error flags are cleared; the transceiver is enabled; the Tx pin is set to a default state of 1, and the timer is configured for the input capture function in the idle state of WAITING_NEWFRAME. The timer configuration is performed in the **ChangeTimerConfig() Function**.

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ChangeTimerConfig() Function

The ChangeTimerConfig() function is responsible for the timer configuration. The timer can be configured to function as either input capture or as overflow using one byte as a parameter.

If the timer is configured as input capture (parameter=0x00), the timer will be configured to interrupt either with the rising or falling edge if trimming is in process, or only the falling edges if in any other state.

If the timer is configured as overflow, the timer pin will be under port control and the timer will overflow every bit-time. If the internal clock is not fast enough for a High_Speed LIN, the timer must be configured to overflow sometimes at one-half bit-time.

WAITING_NEWFRAME State

After the driver is initialized, it will be waiting in an idle state called WAITING_NEWFRAME. In this state, the program will wait for bus activity (a dominant state) which could be the beginning of a new frame. Activity will be detected by the input capture function of the timer, and the possible break is validated and jumps to the next state: RECEIVING_BREAK.

RECEIVING_BREAK State

After a possible break is detected, it should be validated in this state. Basically, the routine must check whether (during a defined number of bits) the state of the Rx pin remains low. This is accomplished with the process illustrated in **Figure 4**.

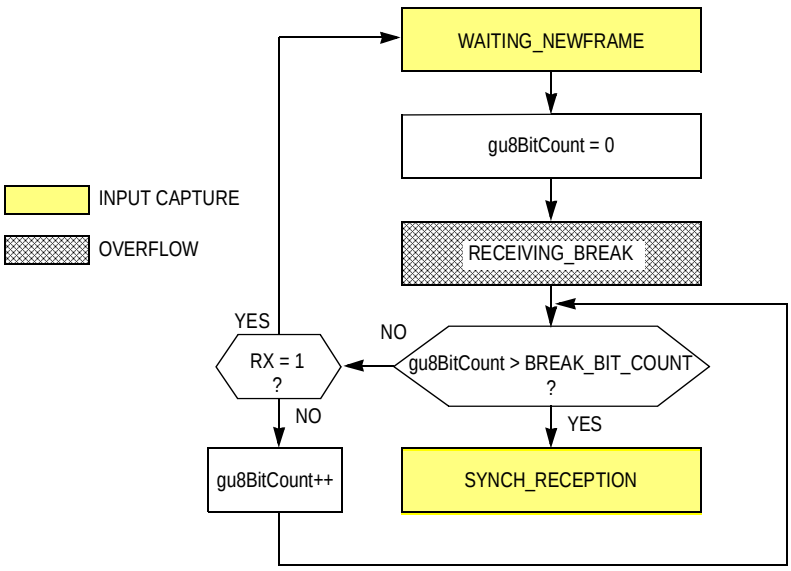

Figure 4. RECEIVING_BREAK Flowchart.

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In this way, the Rx pin will be checked every bit-time. If during one of these checks the Rx is high, the break is invalid and discarded. The desired timing diagram for this state can be seen in **Figure 5**.

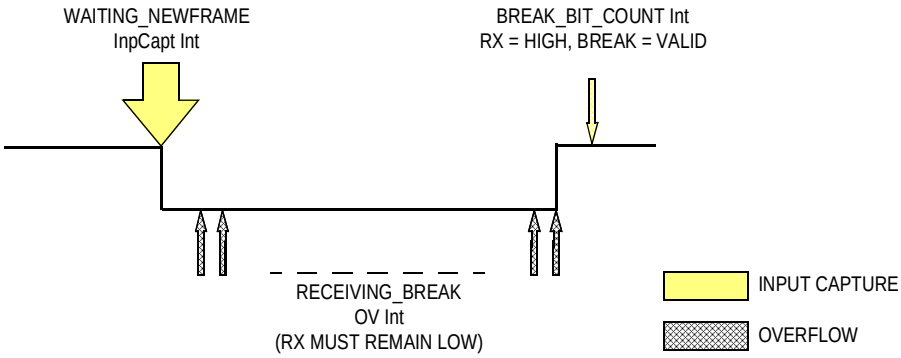

Figure 5. Break Timing Diagram

Synch_Reception State

After the break is validated, the next field is the synch field. Because 0x55 is expected, the MCU will use this field to synchronize with the master timer. If the external oscillator is used, this process is not necessary and the program must only wait for this byte to pass.

Trimming

The trimming process is very important in LIN because it allows inexpensive MCUs to implement LIN using an internal oscillator. Because internal oscillators are not within an acceptable tolerance by default, they must be trimmed to an acceptable tolerance in order to communicate properly.

This is accomplished by performing some relative calculations based on the time elapsed between bit-times. This function is implemented as seen in **Figure 6**.

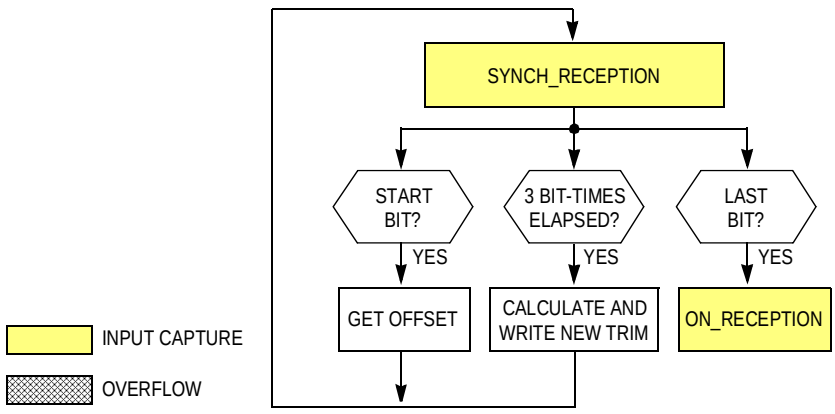

Figure 6. SYNCH_RECEPTION Flowchart

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The calculation of the new trim value is performed using a previously read offset and the time elapsed in the internal clock during three bit-times, based on equation 1:

EQUATION 1: $$EXPECTED_VAL = \frac{f_{Bus} \times INT_COUNT}{Prescaler \times f_{LIN}}$$

WHERE:

f_{Bus} IS MCU INTERNAL BUS FREQUENCY

f_{LIN} IS LIN BAUD RATE

INT_COUNT IS NUMBER OF INTERRUPTS TO COUNT TO OBTAIN AN EXPECTED VALUE (IN BIT-TIMES)

PRESCALER IS TIMER PRESCALER

EXPECTED_VAL IS THE EXPECTED VALUE TO BE READ WHEN INT_COUNT IS REACHED

Because a change in the OSCTRIM register is equal to approximately a 0.2% change in the internal frequency, equation 2 is derived from equation 1:

EQUATION 2: $$1 = \frac{f_{Bus}(0.002) \times INT_COUNT}{Prescaler \times f_{LIN}}$$

USING:

f_{Bus} = 3.2 MHz

f_{LIN} = 9600 bps

THE EXPECTED VALUE FOR $\frac{INT_COUNT}{Prescaler}$ IS $\frac{3}{2}$

SO: INT_COUNTER = 3
PRESCALER = 2

With these values, every variation from the expected value will represent a 0.2% change in the oscillator and thus a direct (1:1) change in the OSCTRIM register.

Because EXPECTED_VAL = 500 and the internal oscillator can vary ±25%, the possible values to be read are:

500 + 25% = 625 (0x271) — Maximum
500 – 25% = 375 (0x177) — Minimum

Consequently, to use only one byte, all values will be added with an offset:

0x271 + 0x89 = 0x2FA — Maximum
0x177 + 0x89 = 0x200 — Minimum
0x1F4 + 0x89 = 0x27D — Expected

In this way, the high byte can be discarded and every change from the expected value (0x27D) will represent a direct change in the OSCTRIM register.

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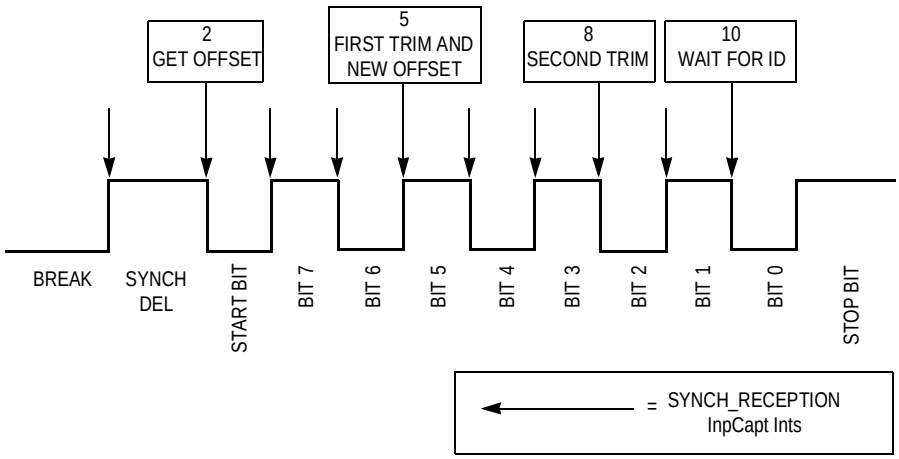

Figure 7. SYNCH_RECEPTION Timing Diagram

ONRECEPTION State

After the synch field is received, the next state will wait for the start bit of the next field, the identifier field. After the start bit is detected using the input capture functionality, all the eight bits representing the ID must be received. This process is performed in the RECEIVING_DATA state.

RECEIVING_DATA State

After the start bit is detected, the timer is configured to overflow on every bit-time to capture all eight bits as shown in **Figure 8**.

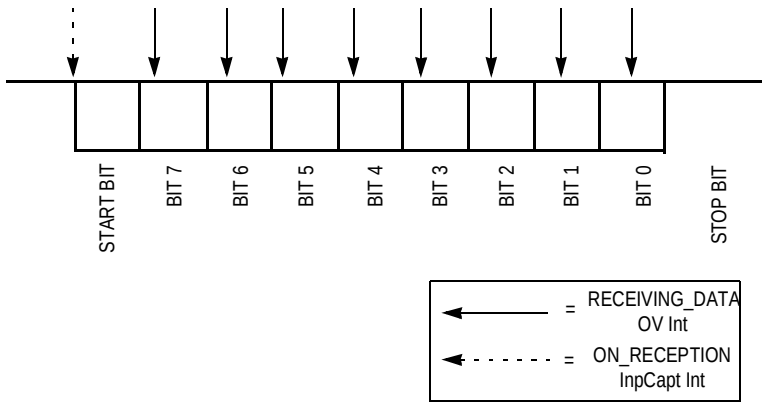

Figure 8. Byte Reception Timing Diagram

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GetChar() Function

After the byte is received, the GetChar() function handles the byte in one of two ways, depending the byte type.

- Byte received is an ID — These steps must be performed:
  1. The parity error is checked based on a mixed-parity algorithm
  2. The ID is validated based on a ROM table and using FindInTable() function
  3. If the ID is defined, the length and direction (transmission or reception) is obtained
- Byte received is data — A previously received ID defined the direction as reception, and data is received by following these steps:
  1. Save the data received in the predetermined buffer
  2. If the buffer was received (based on the defined length), the checksum is calculated using CalcCheckSum() function
  3. If the checksum is correct, the buffer is tested to determine if byte is a SleepMode command.
  4. If it is a SleepMode command, the MCU enters low power-consumption mode.
  5. If it is a normal frame, the MCU will wait for the next frame.

This process can be seen in **Figure 9**.

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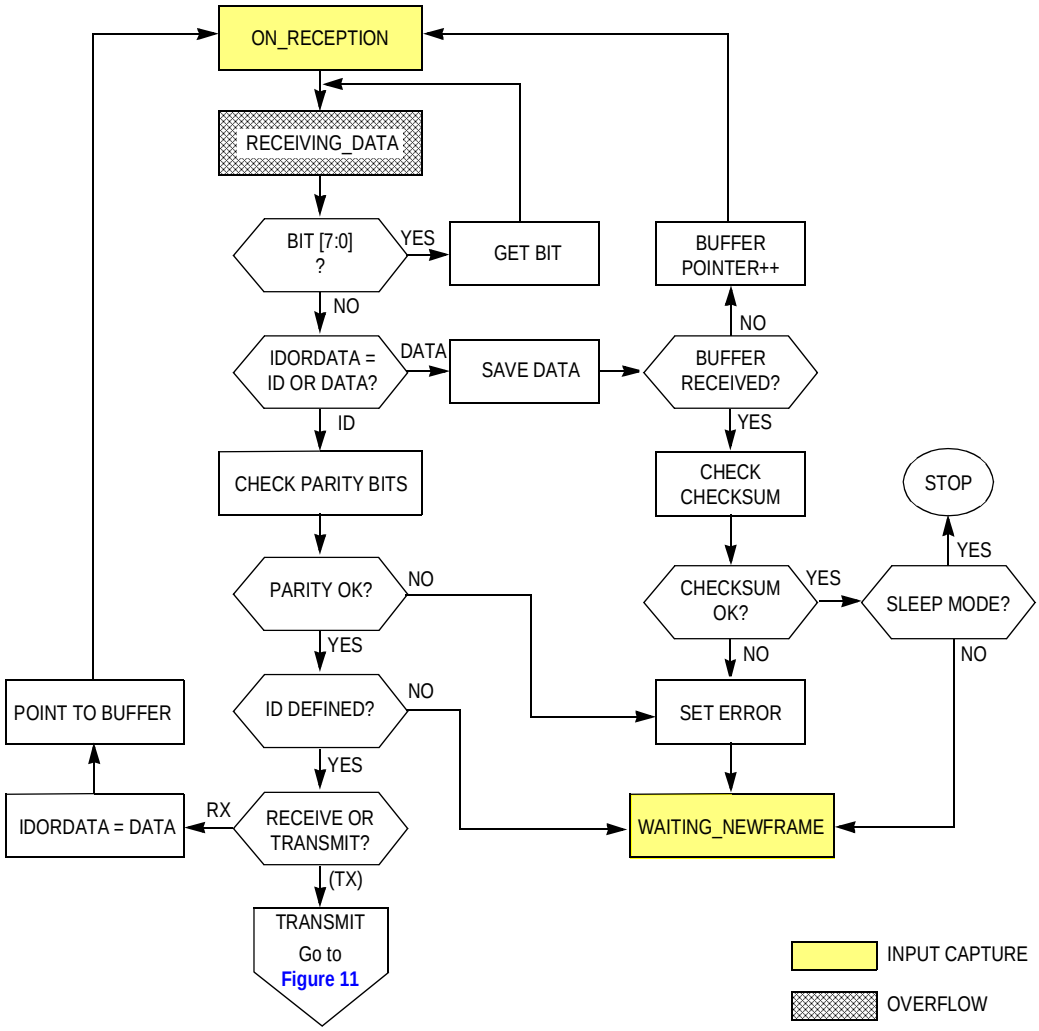

Figure 9. Reception Process Flowchart

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FindInTable() Function

Use this simple look-up function when a small ROM table is defined for space purposes. The function starts looking for an ID from the bottom of a table to the first of its elements. It can increase overhead, but it is very useful for code sizing purposes. Because it is written in assembly, it executes quickly.

FindInTable() function code:

```
UINT8 FindInTable(UINT8 temp)
 {
                  asm{
                                    LDA temp
                                    STA gu8P1
                                    LDHX #POINTER_TO_LAST
                                    LDA #LIN_MSGS
                                    LOOP:
                                                PSHA
                                                LDA gu8P1
                                                CMP ,X
                                                BNE NE
                                                PULA
                                                DECA
                                                BRA END
                                                NE:
                                                TXA
                                                SUB #3
                                                TAX
                                                PULA
                                                DBNZA LOOP
                                                LDA #0xFF
                                    END:
                                    STA gu8P1
                           }
                           return gu8P1;
```

CalcCheckSum() Function

This function is used to check the integrity of a frame calculating the checksum of the buffer using modulo-256 sum. This functionality can be enabled or disabled in compiler options.

Sample() Function

This function is used when the integrity of data is very important and there is a lot of noise in the environment. Each bit is sampled four times, obtaining the most common value in the sample and flagging an error when values obtained vary from each other. This function is not recommended in most cases because it increases the code, it is not specified in LIN, and it can increase overhead (which creates problems with synchronization). The user has the option to enable it or disable it.

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Transmitting State

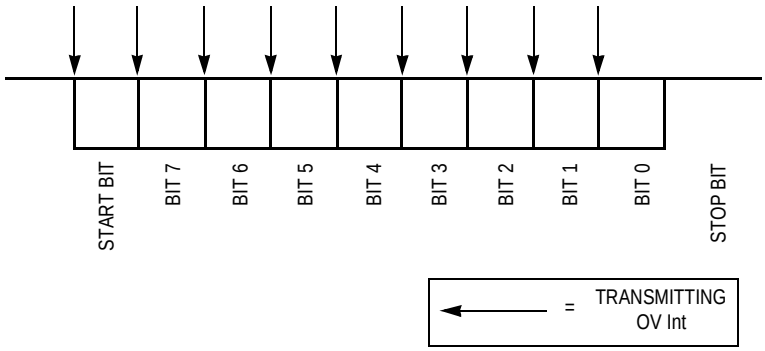

Figure 10. Byte Transmission Timing Diagram

After a byte is sent, the PutChar() function will decide whether another byte must be sent or the transmission must end. The complete flowchart for LIN transmission can be seen in **Figure 11**.

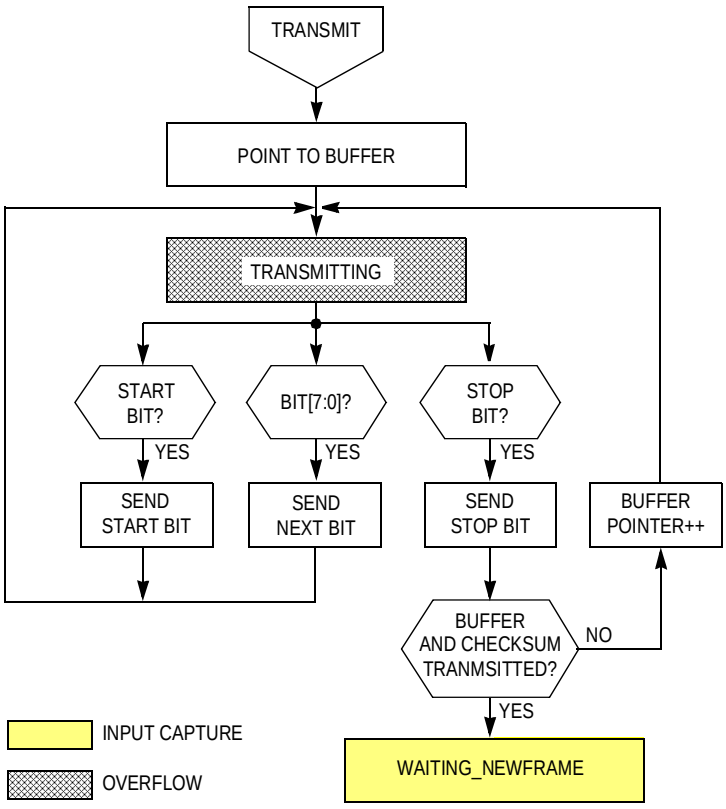

Figure 11. Transmission Process Flowchart

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InitializeMsgTransmission() Function

This function initializes the transmission process. It sets all the needed variables to the proper state, calculates the checksum for the buffer to be sent, and points to the first element of the buffer.

PutChar() Function

This function controls the transmission flow, either terminating the transmission (if the last byte was sent) or setting the next byte in the buffer to be sent.

Sleep Mode Functionality

Sleep mode is compatible with LIN Specification 1.2 and earlier and must be enabled manually. When a sleep mode command is detected, the MCU will enter low-consumption mode. The MC68HC908QY MCU uses stop mode, which stops all activity including timers. This will reduce current consumption from approximately 4.5 mA to less than 0.22 mA. The MCU will wake up only with a keyboard interrupt (KBI), an external interrupt (IRQ), or a reset. In this driver, IRQ is enabled before entering this mode and is the only way to wake without resetting the MCU. This functionality can be implemented with or without a transceiver.

If a transceiver is not used, the Rx pin must be tied with the IRQ pin, so that when a 0 (dominant state) is received, IRQ will be latched and the MCU will wake up.

If a LIN transceiver is used, there are two options:

- Use the INH functionality of the MCU connected to IRQ so that it can wake up.
- Use a voltage regulator where the INH pin is connected to a shutdown pin in the regulator and it is turned off. After some bus activity, the regulator will enable its voltage output and will turn the MCU on. In this case, the MCU will be reset and proper steps must be taken to avoid losing information.

Wake Up

The MCU will wake up with an external interrupt or if a reset occurs. If a reset occurs, the complete driver will be re-initialized and information in buffers will be lost. In case of an external interrupt, all activity will continue. IRQ will be disabled until a new sleep mode is detected and the transceiver (if used) will be enabled.

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Driver Configuration

To provide the required functionality, modularity, and small code size, three files must be configured with user options. These files contain definitions for enabling/disabling different functional modules, defining IDs to be used, and other configuration options. All macros must be configured properly; if the declaration is not as stated, the driver may not work properly.

lincfg.h Description

This file is used to configure the LIN driver as needed by the application. Three main parts can be distinguished:

- Modular macros — Depending on the options enabled, code and overhead will increase. Depending on the combination used, the desired baud rate may not be reached. **Table 2** explains all the options available, the possible values, and the increment in code. The common implementation of this driver (based on LIN specifications) uses 950 bytes with the following options:
  - Includes main.c example.
  - Using internal oscillator
  - 9600 baud rate
  - Rx and Tx pins
  - Timer channel 1 is used
  - Using a transceiver
  - Error checking (bit error, parity and checksum)
  - Sleep mode V1.2 enabled
  - No quick commands
  - Using smaller ROM table with seven IDs defined

All of the code increments shown in **Table 2** are based on these arguments, and they can reduce code as much as 300 bytes, leaving only 655 bytes of code.

- Constants and media access macros — Options changeable according to the hardware used and depending on the application. **Table 3** explains these options and the possible values.
- Auto-calculated macros — Defined automatically with modular macros options and allow the use of bidirectional mode and different channels from the timer. **Table 4** explains all the macros defined here.

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Table 2. Modules

Functionality	Possible Values	Description	Size Increment
Oscillator Mode	INT_OSC	Internal oscillator is used. Synch field used to trim the internal oscillator. Very useful to reduce costs.	+0
	EXT_OSC	External oscillator is used. Because no trimming is performed, code is reduced. Useful to increment the internal frequency (if a fast oscillator is used) but more expensive.	–93 bytes
LIN Baud Rate	MEDIUM_SPEED	Predefined baud rate for medium LIN speed of 9600 bps.	+0
	HIGH_SPEED	Predefined baud rate for high LIN speed of 19200 bps. Code increments because adjustments must be made to accomplish this baud rate.	+18 bytes
	SLOW_SPEED	Predefined baud rate for slow LIN speed of 2400 bps. Code increments because adjustments must be made to accomplish this baud rate.	+12 bytes
Number of Pins Used	One Pin	Timer channel pin used is used as Rx and Tx. Useful when testing with a CPU serial port using only one line (using the same PTA0 used for MON08 communication).	+0
	Two Pins	Timer channel pin is used as Rx pin only and a general-purpose pin is used as Tx only. Used more often because it accommodates transceivers.	+0
Timer Used as Rx	TIMER_USED_1	Timer channel 1 (PTA1) is used as Rx. Very useful when used with MON08 because PTA0 can be used at the same time for monitor mode communication. Ensure that it has a high value when entering monitor mode.	+0
	TIMER_USED_0	Timer channel 0 (PTA0) is used as RX. Very useful when the same line for monitor mode is used for testing with a CPU serial port. Monitor mode can be used for programming purposes only, not for debugging.	+0
Use of Transceiver	ENABLE_TRANSCEIVER	Transceiver is used. It must be properly enabled/disabled	+0
	DISABLE_TRANSCEIVER	Transceiver is not used. Useful for testing purposes with a CPU.	–10 bytes

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Table 2. Modules (Continued)

Functionality	Possible Values	Description	Size Increment
Bit Error Checking	CHECK_BIT_ERROR	Bit error (defined in LIN specification)(1) is checked. Useful for LIN specification compliance.	+0
	NO_CHECK_BIT_ERROR	Bit error is not checked. The Tx pin will transmit regardless of what it reads. Useful when this error is not important or when the master can handle it properly.	–60 bytes

1. For a link to the complete LIN specification, see **References and Recommended Links**.

Table 3. Modular Macros in lincfg.h

Functionality	Possible Values	Description	Size Increment
Parity Error Checking	PARITY_ERROR	Parity error (defined in LIN specification)(1) is checked. Useful for LIN specification compliance.	+0
	NO_PARITY_ERROR	Parity error not checked. Useful when checksum is sufficient to check data integrity or if the master can handle a possible error.	–95 bytes
Multi Sample on RX	MULTI_SAMPLE	Multi sample is enabled. Four samples are performed when reading data from Rx. Useful when noise may be an issue. Not recommended because of the overhead, and it can cause the LIN driver to fail if the oscillator is too slow and the baud rate is high.	+34 byes
	NO_MULTI_SAMPLE	Single sample. Only one sample is taken from Rx. Useful most of the time and can be enough for most applications. LIN specification does not state how data must be sampled.	+0 bytes
Sleep Mode	DISABLE_SLEEP	Sleep mode is disabled. Used when there is no need to enter low power-consumption mode.	–46 bytes
	ENABLE_SLEEP_1_0	Sleep mode (LIN versions earlier than V1.2) is enabled. ID is 0x00.	–2 bytes
	ENABLE_SLEEP_1_2	Sleep mode (LIN V1.2) is enabled. ID is 0x3C and first data is 0x00.	+0

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Table 3. Modular Macros in lincfg.h (Continued)

Functionality	Possible Values	Description	Size Increment
Enable Quick Commands	QUICK_COMMAND	Quick commands are enabled. A function named QuickAction() is performed immediately after receiving a new frame, which allows for immediate action to be taken. If QuickAction() is too big, the next frame can be lost.	+4 bytes +QuickAction() function
	NO_QUICK_COMMAND	After receiving a new frame, it is only written to its buffer and user must handle it properly.	+0
ROM Table Used	SMALLER_TABLE	A smaller ROM table is defined in ROM memory. Useful when there are few IDs defined because code is smaller, but it will increase overhead because of a look-up table function. Do not use if there are too many IDs defined.	+3 bytes per extra ID (lookup function uses 40 bytes)
	FASTER_TABLE	A complete ROM table is defined in ROM memory with all IDs defined in a vector. Useful when there are too many IDs defined and a look-up table is not needed, and when overhead must be reduced. However it will increase the code substantially.	+128 bytes non-dependant of IDs. (–14 used in 7 IDs example)

1. For the complete LIN Specification, see **References and Recommended Links**.

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Table 4. Constants and Media Access Macros in lincfg.h

Constant	Possible Values	Description
BREAK_BIT_COUNT	Unsigned 8 bits	Number of bit counts in order to recognize a valid break.
PRE_TRIMMED_VALUE	Optional or unsigned 8 bits	Pre-trimmed value from factory to load into OSCTRIM register. Use optional if this register (20xFFC0) has a pre-trimmed value from factory. If this value was erased, write your own using any unsigned 8-bit value.
SET_OUTPUT_PIN	Set Tx high	When two pins are used, Tx must be as an output high when initializing LIN. This macro must set this condition.
TWOPINS_TX_HIGH	PTx_PTxx=1	Used to set Tx in high state. Ensure that the Tx pin is mapped here.
TWOPINS_TX_LOW	PTx_PTxx=0	Used to set Tx in low state. Ensure that the Tx pin is mapped here.
TRANSCEIVER_ENABLE	Set transceiver EN pin high	If a transceiver is used, this macro enables the transceiver when LIN is initialized. Ensure that the pin connected to the transceiver's EN pin is mapped here.
TRANSCEIVER_DISABLE	Set transceiver EN pin low	If a transceiver is used, this macro disables the transceiver when LIN is initialized. Ensure that the pin connected to the transceiver's EN pin is mapped here.
LIN_BAUDRATE	A LIN baud rate	This macro is obtained automatically based on the LIN baud rate defined. To use a different baud rate, see **trimcfg.h Description**
MCU_Fbus (f_{Bus})	MCU internal operating frequency	This macro is obtained automatically based on the oscillator mode used. f_{Bus} must remain the same, but the external frequency can change according to the external oscillator used.

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Table 5. Auto Calculated Macros In lincfg.h

Macro	Description
TSCCHREG	Timer channel control register
TSCCHF	Timer channel overflow flag
TIM_CH_INT_VECTOR	Timer channel interrupt vector
ACK_INPCAPTUREINT_CH	Timer channel interrupt acknowledge
TCHLREG	Timer channel low register
ONEPIN_TX_HIGH	Set high Tx output pin if using bidirectional mode
ONEPIN_TX_LOW	Set low Tx output pin if using bidirectional mode
is_RX_HIGH	Check whether Rx pin is high
is_RX_LOW	Check whether Rx pin is low
SET_TX_HIGH	Set Tx pin high
SET_TX_LOW	Set Tx pin low

trimcfg.h Description

This file is used to define all macros and constants used for the trimming process defined in **Trimming**. The definitions used here are calculated for the recommended bit rates for LIN. If the baud rate will be changed, the user must configure this file properly including according to the section above.

All the constants declared in this file can be seen in **Table 6** with a brief description.

Table 6. Constants Defined in trimcfg.h

Macro	Description
VARIATION	Allowed variation for internal oscillator. Defined by user.
START_BIT_COUNT	Number of bit counts for the start bit.
TRIM1_COUNT	Number of bit counts to wait for the first trim calculation.
TRIM2_COUNT	Number of bit counts to wait for the second trim calculation.
STOP_BIT_COUNT	Number of bit counts for the stop bit.
INT_COUNT	Number of bit counts elapsed from offset to trim calculation.
PRESCALER	Timer prescaler to perform a correct trimming.
PS_VALUE	Value loaded into timer control register to set prescaler. Prescaler = 2^{PS_VALUE}.
EXPECTED_VAL	Expected value to be read if the internal clock is 3.2 MHz.

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Table 6. Constants Defined in trimcfg.h (Continued)

Macro	Description
MAX_VALUE	Maximum possible value to be read (3.2 MHz + 25%).
MIN_VALUE	Minimum possible value to be read (3.2 MHz – 25%).
u8_TO_SCALE	Value to be added in order to use only chars and discard the high byte.
u8_MID_EXPECTED	Expected scaled value. Compared with the read value to check variation.
u8_MAX_EXPECTED	Maximum allowed value based on the variation defined.
u8_MIN_EXPECTED	Minimum allowed value based on the variation defined.

linmsgid.h Description

Use this file to define all the valid identifier fields and their functions. Code size depends on the number of IDs defined. These IDs and the total number of IDs used must be defined correctly to ensure proper functionality of the LIN driver. If the application requires the use of many IDs, use the FASTER_TABLE definition described in **Table 3**. This is recommended because the ROM table will remain the same and the FindInTable() function will not be used, reducing the overhead. If SMALLER_TABLE definition is used, the code will be smaller and the FindInTable() function will look up the ID(s) in the ROM table. In this case, each ID defined will increase code size by four bytes.

The ID definition must follow these steps:

1. Define the location of ROM table in MESSAGES_ROM_ADDRESS constant.
2. Define number of IDs to use (including reserved commands if used) in LIN_MSGS.
3. Comment or erase all the unused IDs and define the ones to be used. LIN_MSG_xx must contain the direction of the ID and LIN_MSG_xx_LEN must contain the data length(1)

Table 7 shows all the constants used in this file.

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Table 7. Constants Defined in linmsgid.h

Macro	Description
MESSAGES_ROM_ADDRESS	Start address for the ROM table (16 bits).
LIN_MSGS	Number of IDs defined (1 to 64 bits).
LIN_MSG_xx(1)	Direction of ID: LIN_RECEIVE — Data will be received in the buffer when an ID arrives. LIN_SEND — Data in buffer will be sent when an ID arrives.
LIN_MSG_xx_LEN(1)	Length of data (buffer) to be received. (1–8 bits)
POINTER_TO_LAST	Auto-calculated pointer points to the last ID in ROM table. Do not change.

1. Where xx is the ID number in hexadecimal format

Hardware Implementation

This LIN driver is intended to be flexible with user hardware. This demonstration is implemented in MC68HC908QY4 slave LINkit hardware (see **Schematic**).

MC68HC908QY4 Signal Description

The main features of the MC68HC908QY4 MCU are:

- 4 K of FLASH memory (1.5 K in the MC68HC908QY1/QY2)
- 128 bytes of RAM memory
- No SCI module
- Some pins share functionality (ADC, TIM, KBI, OSC, $\overline{\text{IRQ}}$, and $\overline{\text{RST}}$).
- One timer with two channels (TIMCH0 and TIMCH1)
- Timer has input capture, output compare and overflow functionality.
- External interrupt ($\overline{\text{IRQ}}$) available at PTA2.
- Reset ($\overline{\text{RST}}$) available at PTA3, not enabled by default.
- Oscillator (OSC) pins available at PTA4/PTA5.
- One general-purpose only 8-bit port (PTB).
- PTA0 (TIMCH0) is used to enter monitor mode and program the MCU.
- PTA1 (TIMCH1) must be tied high when entering monitor mode.
- Internal oscillator available; external oscillator can be used.
- Internal frequency using internal oscillator is 3.2 MHz ±5% before trimming.

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The driver is designed to use as few pins as possible to reserve some for the application. The pin usage is described in **Table 8**.

Table 8. MC68HC908QY4 Pin Usage

Pin	Use	Comments
PTA0/AD0/ TCH0/KBI0	MON08 Comm	Used for programming/debugging. Can be used to test driver with CPU in bidirectional mode (no debug). One timer channel is available in real application.
PTA1/AD1/ TCH1/KBI1	LIN reception (Rx)	Must be tied to V_{DD} when entering monitor mode (disconnect when using a transceiver). Reception only when using the transceiver. One timer channel is available in real application.
PTA2/$\overline{IRQ}$/ KBI2	Programming voltage	Used for programming only. Can be used to wake up the MCU without a regulator (not in this board). Available in real application.
PTA3/$\overline{RST}$/ KBI3	Reset	Available in real application.
PTA4/OSC2/ AD2/KBI4	Not used	Must be tied to GND/V_{SS} when entering monitor mode. Available in real application.
PTA5/OSC1/ AD3/KBI5	9.8304 MHz oscillator.	Used for programming. Can be used instead of internal oscillator. Available in real application.
PTB0	Push button	Available in real application.
PTB1	Not used	Available in real application.
PTB2	LIN transmission (Tx)	One general-purpose pin for transmission is needed in real application when using a transceiver.
PTB3	LED	Available in real application.
PTB4	LED	Available in real application.
PTB5	LED	Available in real application.
PTB6	LED	Available in real application.
PTB7	LIN transceiver enable	One general-purpose pin to enable the transceiver is needed in real application when using a transceiver.

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MC33399 Description

Another important component in the board is the MC33399, the LIN transceiver. This transceiver is a physical layer component dedicated to automotive sub-bus applications. It is compliant with LIN specifications, sleep mode, and wake up capability. The transceiver can wake up from sleep mode with three different events:

- Wake-up signal from the wake pin
- Active signal in EN pin
- LIN bus activity

The last two events will be used in this board. The pin description for this transceiver can be found in **Table 9**.

Table 9. MC33399 Pin Usage

Pin	Description	Use	Connection
Rx	LIN reception	Reports the state of the LIN bus voltage.	PTA1 in MC68HC908QY4
EN	Transceiver enable	Controls the operation mode (active or sleep).	PTB7 in MC68HC908QY4
WAKE	Wake input	High-voltage input used to wake the device from sleep mode.	GND
Tx	LIN reception	MCU interface that controls the state of the LIN output.	PTB2 in MC68HC908QY4
GND	Ground	Provides ground (V_{SS}).	GND
LIN	LIN bus	The single-wire bus transmitter and receiver.	Pin 4 of connector LIN MOLEX
V_{SUP}	Power supply	Provides power supply (7 to 27 V).	V_{SUP}
INH	Inhibit	Used in this board to control an external switchable voltage regulator. Can be negated and used as an external interrupt to wake the MCU.	SHDN pin in regulator

Voltage Regulator

This board also includes a voltage regulator with shutdown capability which supplies all the circuitry, excluding the LIN transceiver. This will enable the transceiver to wake all the components when LIN bus activity is detected.

Headers, Jumpers, and Connectors

This board allows for direct connectivity with a LIN bus, at the same time allowing programming and debugging capabilities. This is accomplished by the jumpers described in **Table 10**.

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Table 10. Jumper Description

Jumper	Symbol	Description
J2		IRQ with pullup to V_{DD}
		IRQ connected to V_{tst} (to program the MCU)
J3		PTA1 with pullup to V_{DD} (used to enter monitor mode)
		PTA1 connected to Rx pin
J4		Debug circuitry off (OSC and RS-232 Transceiver)
		Debug circuitry supplied to V_{DD}
J5		9.8304 MHz OSC disconnected
		9.8304 MHz OSC connected to OSC1 (to program the MCU)

There are also two connectors (CON1 and CON2) to connect the board directly to a LIN bus. Their pinouts can be found in **Table 11**.

Table 11. LIN Connectors CON1 and CON2

PIN	Description
1	V_{SS}
2	V_{SS}
3	V_{SUP}
4	LIN
5	V_{SS}
6	V_{SS}

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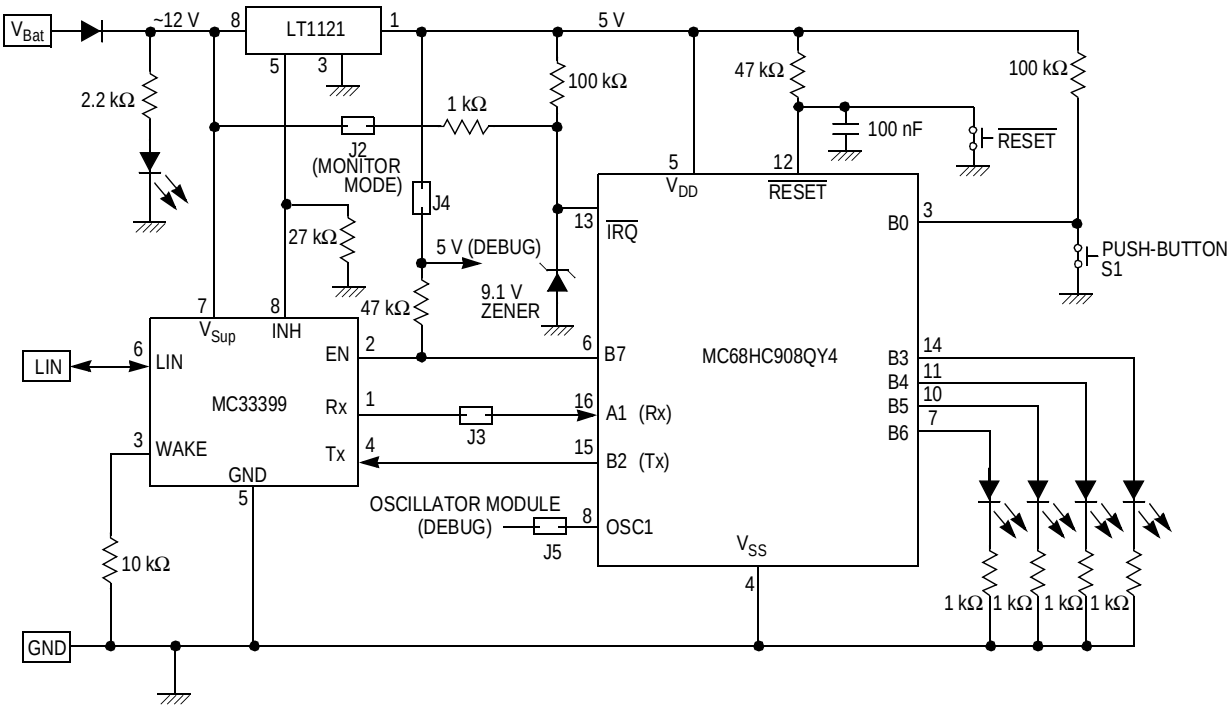
Schematic



Driver Usage and Example

This section shows how to implement the driver with reference to the example project, AN2503SW. This file can be downloaded from the Freescale LIN website, http://freescale.com

Configure lincfg.h

Write lincfg.h according to the implementation needs. Review **lincfg.h Description** for a complete description of this file. In the AN2503SW, the driver is configured as described below:

- Internal oscillator used
- Medium 9600 bps LIN frequency (f_{LIN}) used
- PTA0 used as bidirectional pin for communication
- Transceiver is not used
- Bit error and parity error are checked/enabled
- QuickAction commands are not used
- Smaller ROM table is defined
- Trimmed value of 0x19 is used

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Modify trimcfg.h

Modify this file according to the needs of the application. Review **trimcfg.h Description** for a complete description on this file. In this example, the normal implementation for 9600 bps is used.

Configure linmsgid.h

This file must include the definition of all the IDs used in the application. Review **linmsgid.h Description** for using this file. In this example, the following IDs are defined:

Table 12. Example ID Definitions

ID	Mode	Length
0x00	Reception	2
0x1A	Reception	8
0x1B	Transmission	8
0x1C	Reception	4
0x1D	Transmission	2
0x1E	Transmission	2
0x3C	Reception	8

Write main()

The main files already include the definition for configuration registers and LIN peripherals, but they can be changed by the user if the application requires it. LIN is a one-master/multi-slave protocol, and slaves can't participate on the bus until they are required to. The buffers are updated in the interrupts, and it's the user's responsibility to ensure their proper use. The main file for AN2503SW contains an example of LIN use. Also, keep in mind that any defined buffer can be accessed directly — including the resolver.h file. Any access to the buffers can be direct or indirect (through the use of pointers) to help increase readability.

In AN2503SW, the example sends with ID 0x1B. The first five bytes of the buffer receives ID 0x1A and two error counters (one for reception and one for transmission).

Notice that the sixth element is undefined. Because the buffer isn't initialized, the value will be undefined with the actual RAM value.

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Write QuickAction()

This function is included in slave_drv.c, and it's the only function changeable by the user in a normal application. Use this function when an action must be performed immediately after the ID is received. Remember that functions included in this part must not be extensive unless the LIN master guarantees enough time between LIN transfers. An extensive function can result in an undesired lost of frame. In AN2503SW, the pin PTB3 is toggled every time the ID 0x1A is received with a value of 0x00 in the first byte. However, this function is not defined because the QUICK_COMMAND definition is not used.

Compile and Download Your Application

Check for any errors in compilation and download your application to the MCU. Remember that the MCU must enter monitor mode and some signals are required:

- PTA0 for MON08 communication
- PTA1 tied to V_{DD}
- PTA4 tied to GND
- $\overline{IRQ}$ tied to V_{tst}

Any change in these signals could result in programming errors. Check the board jumpers.

Test Your Application

There are several ways to test and debug your application depending on the application:

- A computer program can be easily implemented to test your IDs and the response of the MCU.
- If the project is in development or for a quicker design without using a transceiver, use PTA0 as bidirectional line and test it with the same hardware used for programming the PC.
- A simple transceiver with an RS-232 to a TTL converter can help you to use your PC as a LIN master.
- The LIN frames are very easy to see and recognize with the aid of an oscilloscope.

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LIN Driver Features and Performance Comparison

The Freescale LIN website contains application notes and drivers for different implementations. So, you can find the design that best matches your application. Some influential factors affecting your MCU decision could include:

- Master/Slave tasks or only slave tasks
- Memory requirements
- Number of available pins
- Other physical interfaces (SPI, IIC, LCD, etc.)
- Development time
- Cost

The application described in this documents is intended to cover the lowest-end part of the LIN portfolio, meaning:

- **Only slave tasks** — This driver implements only slave tasks, meaning that the node must be a slave, executing commands and sending data only by master requests.
- **Low memory requirements** — This driver is intended to be used in a member of the MC68HC908QT/QY Family, whose members have 1.5K and 4K FLASH. This driver uses approximately between 600 bytes to 1K, allowing the user to implement the driver in the smallest MCU from Freescale with enough space for a small application.
- **Low number of available pins** — This family has members with 8 pins (6 I/O) or 16 pins (14 I/O), and the driver can use as few as 1 to 4 pins.
- **No physical interfaces** — This family is a low-level general-purpose family, so it doesn't include any special distinctive feature, except the ADC pins and the internal modules.
- **Decreases development time** — There are several hardware options for a LIN implementation including (from simplest to most complex): the SLIC (slave LIN interface controller), ESCI (enhanced serial communication interface), SCI (serial communication interface), and bit-banged timer. However, this driver is intended to reduce the development time because the user doesn't have to worry about the implementation, only to develop his or her own code.
- **Lowest cost** — The most important feature about this driver is that it allows a LIN implementation in the least expensive and smallest Freescale MCU.

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Other distinctive features of this application note that the user must consider:

- **Use of API** — This application note doesn't use an API. This represents an incompatibility with some other application notes, but it reduces the CPU use and the amount of memory used. It's a good option to leave more free memory for the user program.
- **Memory usage** — Table 13 shows a comparison between different implementations of LIN drivers in other available application notes.
- **CPU time and performance** — Table 14 shows the differences between the CPU time and performance in different MCUs and application notes.

Table 13. Driver Performance Metrics

	Version	Std API	Feature Level	Driver Code Resource Required		
				RAM (Bytes)	ROM (Bytes)	Stack (Bytes)
TIM08	QY/QT bit-banged drivers AN2503/D(1)	N	MIN	24 (+ 8 per 8 byte msg)	536 (+ 3 per msg)	22
			MAX		836 (+ 3 per msg)	22
	QY/QT bit-banged drivers AN2599/D	Y	—	32 (+12 per 8 byte msg)	1103 (driver) 487 (API)	35
ESCI	EY16 ESCI drivers AN2575/D(2)	Y	—	19 (+1 per 8 byte msg)	1130 (driver + API)	< 25
SLIC	LINQL4-ASM	N	—	11 (+ 8 per 8 byte msg)	172	7
	LINQL4-C	N	—	18 (+ 8 per 8 byte msg)	120	20
	LINQL4-API	Y	—	32 (+ 12 per 8 byte msg)	838 (driver) 420 (API)	35

1. AN2503/D driver assumptions:
   MIN = external OSC, 9600bps, no SLEEP mode, no parity check, no bit error checking
   MAX = internal OSC, 19200bps, SLEEP, parity checking, and bit error checking enabled
   Each also has 7 messages defined, using 26 bytes of RAM

2. AN2575/D memory usage data comes from LIN08 driver manual for EY16.

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Table 14. Driver Performance Metrics

	Version	Std API	No. of Interrupts/ Msg Frame (8-byte msg)	LIN Bus Speed	CPU Speed (MHz)	CPU Usage[1]	
						Average[2]	Peak
TIM08	QY/QT bit-banged drivers AN2503/D	N	111 Rx[3] 120 Tx	9,615 19,230	3.2	14% (rx) 20% (tx) 29% (rx) 40% (tx)	193 µs
	QY/QT bit-banged drivers AN2599/D	Y	97 Rx 106 Tx	9,615 19,230		20% (rx) 20% (tx) 38% (rx) 44% (tx)	272 µs
ESCI + TIM08	EY16 ESCI drivers AN2575/D	N	12	9,615 19,230	3.2[4] (calculated)	2% (rx) 4% (tx) 4% (rx) 7% (tx)	39 µs
SLIC	LINQL4-ASM AN2633/D	N	2	9,615 19,230	3.2	0.3 (rx) 0.2 (tx) 0.5 (rx) 0.5 (tx)	34 µs
	LINQL4-C AN2633/D	N		9,615 19,230		0.4 (rx) 0.4 (tx) 0.8 (rx) 0.8 (tx)	61 µs
	LINQL4-API AN2633/D	Y		9,615 19,230		0.8 (rx) 0.8 (tx) 1.6 (rx) 1.7 (tx)	123 µs

1. CPU usage represents the time spent in the communication ISR(s) vs. time spent doing other tasks. API functions and handling performed outside of the ISR(s) is not counted against this metric. Average value is reported as a percentage of times, but is still a function of CPU speed, as LIN communications is asynchronous to CPU operations. CPU usage numbers are approximate. Peak time represents the longest single interrupt which that be processed.

2. *From LIN08 Driver User's Manual:* CPU performance is calculated as: L = T active / T frame * 100%
   where:
   - L is the CPU load in percent;
   - T active is the amount of CPU time expended in executing the driver code during T frame;
   - T frame is the amount of time required to transmit or receive a regular LIN bus frame of maximum length, containing 8 bytes of data (124 bits). The required LIN message budget of 40% is also taken into account. For Reference: T frame (9615 bps) = 18.055 ms; T frame (19230 bps) = 9.028 ms.

3. For received data (command) messages, 0x55 data and checksum used for worst case ISR load.

4. EY16 CPU usage information was measured based on 4.9152 MHz CPU frequency, then recalculated for a 3.2 MHz CPU frequency.

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Freescale offers a complete portfolio for LIN applications. This allows the user to choose the best options according to the particular application—from the lowest end MC68HC908QT/QY design with low CPU, memory, and pin requirements, to a higher performance MC69HC908QL design with dedicated hardware and more available CPU and memory for the user. The options extend to higher requirements and master nodes, including some high-end HC08 members and some 16-bit families like the HCS12.

AN2503 is a low-end driver oriented to small, non-intensive applications for users needing flexibility, optional features, time predictability for all messages and most of all, very low cost.

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References and Recommended Links

Links

LIN consortium web page
www.lin-subbus.org

Freescale semiconductors main page
www.freescale.com

Freescale LIN (including products, documentation, and applications)
www.freescale.com

Software

AN2503SW: Driver code source described in this document

Documents

MC68HC908QY4/D: Q Family data sheet

AN2103/D: *Local Interconnect Network (LIN) Demo*

AN2205/D: *Car Door Keypad Using LIN*

AN2264/D: *LIN Node Temperature Display*

AN2343/D: *HC908EY16 LIN Monitor*

AN2342/D: *LIN Sample Application for the MC68HC908EY16*

AN2470/D: *MC68HC908EY16 Controller Robot Using the LIN Bus*

AN2573/D: *LIN Kits LIN Evaluation Boards*

AN2575/D: *MC68HC908EY16 ESCI LIN Drivers*

AN2302/D: *EEPROM Emulation for the MC9S12C32*

AN2344/D: *HC908EY16 EMI Radiated Emissions Results*

AN2346/D: *EEPROM Emulation using FLASH in MC68HC908QY/QT*

AN2498/D: *Initial trimming of the MC68HC908 ICG*

AN2560/D: *MC68HC908EY16 IR Receiver for Remote Control of LIN Robot*

AN2575/D: *MC68HC908EY16 ESCI LIN Drivers*

AN2599/D: *Generic LIN Driver for MC68HC908QY4*

AN2633/D: *LIN Drivers for SLIC Module on the MC68HC908QL4*

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